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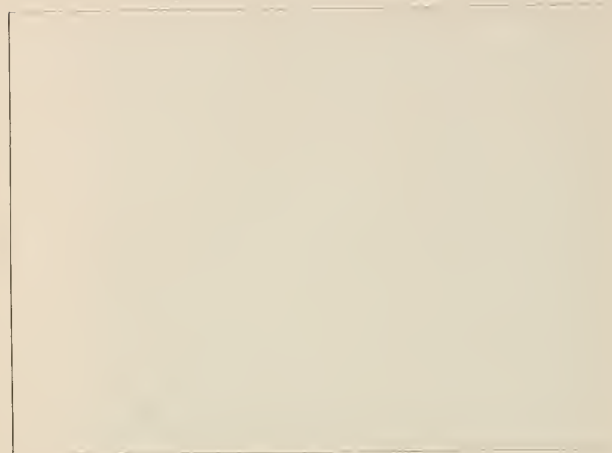
Executive Summary

POTENTIAL USE OF TIRE RUBBER
AND EBONITE IN ASPHALT

Abidin Kaya



PURDUE UNIVERSITY



JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-92/14 ~2

Executive Summary

**POTENTIAL USE OF TIRE RUBBER
AND EBONITE IN ASPHALT**

Abidin Kaya

EXECUTIVE SUMMARY

Synthesis Study

POTENTIAL USE OF TIRE RUBBER AND EBONITE IN ASPHALT

To: Vincent Drnevich, Director
Joint Highway Research Project

May, 1992
Project No: C-36-50M
File No: 2-4-38

From: L.E. Wood
Professor of Civil Engineering
Purdue University
West Lafayette, Indiana

Subj: Synthesis Study on the "Potential Use of Tire Rubber and Ebonite in Asphalt"

Attached is the executive summary on the subject study. The study has been performed by Abidin Kaya, Graduate Research Assistant, under my direction.

This study will be useful in determining physical properties of rubber-asphalt mixes; problems which may be associated with rubber-asphalt mixes; and experiences of other states with rubber-asphalt mixes. The recommendations help INDOT define the technical, economic and environmental feasibility of rubber-asphalt mixes. The report also summarizes knowledge of ebonite as a possible asphalt additive.

The executive summary is submitted for review, comment, and acceptance in fulfillment of the referenced study.

Respectfully Submitted

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EXECUTIVE SUMMARY

Synthesis Study

POTENTIAL USE OF TIRE RUBBER AND EBONITE IN ASPHALT

by

Abidin Kaya

Joint Highway Research Project
Project No.: C-36-50M
File No.: 2-4-38

Prepared as Part of an Investigation
conducted by the
Joint Highway Research Project
Engineering Experiment Station
Purdue University

In Cooperation with the
Indiana Department Transportation
and the
U.S Department of Transportation
Federal Highway administration

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents not necessarily reflect the official views or policies of the Federal Highway Administration. This Report does not constitute a standard, specification, or regulation.

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16. Abstract <p>This report evaluates effectiveness of rubber-asphalt and ebonite-asphalt mixes based on a review of published literature, and unpublished reports. It discusses in detail various aspects of these mixes, including: different applications, physical properties, experiences of state highway agencies, and claimed advantages and problems associated with their use.</p> <p>Although rubber-asphalt mixes have superior physical properties, they have performed either only slightly better or equal to conventional asphalt mixes in the field. The salient problems associated with rubber asphalt mixes which restrict their use are: stickiness, high cost, and air pollution. The cost of rubber-asphalt mixes is much higher than conventional asphalts, and there is little evidence that rubber-asphalt mixes will have an increased service life sufficient to justify the high costs.</p> <p>Ebonite-asphaltic mixes have possible applications assuming that the ebonite can be economically cleaned of lead contamination.</p>			
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POTENTIAL USE OF RUBBER AND EBONITE IN ASPHALT

Background

Improving the quality of asphalt pavements and disposition of scrap tires by adding rubber to asphalt have recently become major issues. Many states have constructed pilot projects to evaluate the effectiveness of rubber-asphalt mixes with different procedures.

National legislator considers legislation to regulate and simulate alternative use of rubber-asphalt mixes. The "Tire Recycling Incentives Act" (H.R.871 and S.396) addresses both regulation and technology issues. Section 1038 of the Intermodal Surface Transportation Efficiency Act (1991) addresses the study and utilization of rubber-asphalt mixes by highway agencies (Heitzman, 1992).

The Indiana Department of Transportation (INDOT) has developed two pilot projects (I 465 and SR 18) to evaluate the effectiveness of rubber-asphalt mixes with a different content of rubber in asphalt in 1991. These two projects are under inspection.

This report, synthesizes information on rubber-asphalt to answer questions that include:

1. How does rubber in asphalt change physical properties of mixes ?
2. What is the experience of other states with rubber-asphalt mixes ?
3. What are the various applications of rubber asphalt mixes ?
4. What, if any, are the problems associated with rubber-asphalt mixes ?.

After a comprehensive literature research, most of the above questions are answered satisfactorily based upon the published literature and unpublished reports.

Rubber-asphalt mixes are used in two different procedures: wet process and dry process. The wet process mixes crumb rubber with aggregate before the mixture is charged with asphalt. This process is called modified rubber asphalt. The dry process blends the crumb rubber with the asphalt cement prior to incorporating the binder into the project. The dry process uses slightly less rubber than the wet process and requires no equipment modification. To improve the efficiency of blending rubber with binder, equipment modification is required (White, 1990).

Applications of Rubber Asphalt Mixes

These applications are:

- joint-crack sealant
- rubber-asphalt stress absorbing membrane (SAM)
- rubber-asphalt stress absorbing membrane interlayer (SAMI)
- rubber-asphalt concrete
- modified rubber-asphalt hot mix (HMA)

The most extensive use of rubber-asphalt is as a joint-crack sealant (Ahmed, 1991). Other applications of rubber-asphalt mixes change from state to state.

Results

Most of the states have at least one experience with rubber-asphalt mixes. Some of the states had poor experiences, whereas others have expressed satisfaction with rubber-asphalt mixes. The Wisconsin DOT has expressed the opinion that the use of tires in asphalt has been a political decision rather than a technical one (Jaskaniec, 1990). States that had poor experiences have discouraged the use of rubber-asphalt mixes.

Ground tire rubber in asphalt changes the physical properties of the mix significantly. In most of the cases, rubber-asphalt

mixes have better physical properties than conventional asphalt. If the usage of rubber-asphalt mixes is based on physical properties of the mix, rubber-asphalt mixes are superior (Takallou et al., 1985, Roberts et al., 1989). Tire rubber may effect the asphalt in the following ways:

- improve the viscosity
- increase the elasticity
- increase the fatigue life
- increase the durability

Viscosity of rubber-asphalt mixes is much higher than conventional asphalt (Takallou et al, 1985, Roberts et al, 1989, Maupin, 1992). Viscosity of the mix is a function of rubber type, size of the rubber particles, and amount of the rubber in the binder. Everything else being equal, 2% or more rubber content can increase the viscosity of mix significantly.

Elastic recovery increases linearly with increasing rubber content. Elastic recovery increases with both temperature and digestion.

Tire rubber in an asphalt mix significantly increases the fatigue life. Fatigue life of the mixes doubles with addition of 5% rubber in hot mix asphalt.

Durability of rubber asphalt mixes is said to be improved due to improved physical properties of mixes. However, this is not proven yet.

Most of these improved physical properties of rubber-asphalt mixes have reported based upon laboratory test results rather than field results. Very few of the states which expressed satisfaction have been reported field experiences of rubber-asphalt mixes.

Based upon improved physical properties, it is said that rubber-asphalt mixes will improve the performance of the pavement including: reduce noise level, increase stopping distance, increase skid resistance and deicing. However, the data presented by different researchers are in contradiction and none of these improved performances has been fully proven in the field yet. Noise reduction is one of these which has been a major argument. Noise reduction ranges from zero to ten dB, which represents 90% reduction level have been presented.

Although ground tire rubber improves physical properties of the mixes, some problems are associated with rubber-asphalt mixes which restricts usage. Some of the these problems are as follows.

- air pollution
- high cost
- stickiness
- equipment modification

Perhaps stickiness and equipment modification can be solved in the long term. However, environmental problems (air pollution) and high cost are major difficulties which should be solved before wide usage of tire rubber in asphalt occurs.

Increased cost of rubber-asphalt mix has been major concern since first test projects. It has been argued that increased performance life will offset the increased cost; however, there is little evidence for this yet.

Ebonite has both desirable and undesirable properties for use with asphalt pavement materials. Desirable properties of ebonite are: strong, lightweight, angular and resistant to abrasion. Undesirable properties of ebonite are: flammability, smooth-sided and the presence of heavy metals (Manke et al., 1965). In this respect, some amount of ebonite can be used as aggregate, assuming that the ebonite is cleaned of heavy metals contamination.

Conclusions

Ground tire rubber in asphalt improves the physical properties of the mix including: viscosity, fatigue life, elastic recovery, skid resistance, and durability.

The improved physical properties should improve the performance of rubber-asphalt mixes, allowing rubber-asphalt mixes to last longer, however there is no large body of evidence to prove this yet.

Some problems are associated with rubber-asphalt mixes which may strictly restrict their use of them. The problems are: high cost, stickiness, smoking, and equipment modification.

Usage of rubber-asphalt mixes should not be encouraged until

INDOT acquires first hand results from pilot projects.

Cleaned ebonite can probably be used as aggregate with asphalt pavement materials. Additional research is required.

Recommendations

Use of rubber-asphalt mixes should be approached carefully until Indiana Department of Transportation finds field performance results in favor of using of them.

Ebonite can perhaps be used with pavement materials to some extent. However, the presence of heavy metals can create environmental problems and care must be taken to be sure they are not present.

Further research is needed on both rubber-asphalt mixes and ebonite-asphalt to draw any solid conclusions.

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JOINT HIGHWAY RESEARCH PROJECT

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Final Report

**POTENTIAL USE OF TIRE RUBBER
AND EBONITE IN ASPHALT**

Abidin Kaya

FINAL REPORT

Synthesis Study

POTENTIAL USE OF TIRE RUBBER AND EBONITE IN ASPHALT

To: Vincent Drnevich, Director
Joint Highway Research Project

May, 1992
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Subj: Synthesis Study on the "Potential Use of Tire Rubber and Ebonite in Asphalt"

Attached is the final report on the subject study. The study has been performed by Abidin Kaya, Graduate Research Assistant, under my direction.

This study will be useful in determining physical properties of rubber-asphalt mixes; problems which may be associated with rubber-asphalt mixes; and experiences of other states with rubber-asphalt mixes. The recommendations help INDOT define the technical, economic and environmental feasibility of rubber-asphalt mixes. The report also summarizes knowledge of ebonite as a possible asphalt additive.

The report is submitted for review, comment, and acceptance in fulfillment of the referenced study.

Respectfully Submitted

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FINAL REBORT

Synthesis Study

POTENTIAL USE OF TIRE RUBBER AND EBONITE IN ASPHALT

by

Abidin Kaya

Joint Highway Research Project
Project No.: C-36-50M
File No.:2-4-38

Prepared as Part of an Investigation
conducted by the
Joint Highway Research Project
Engineering Experiment Station
Purdue University

In Cooperation with the
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LIST of ABBREVIATIONS

ADOT	Arizona Department of Transportation
ADOTPF	Alaska Department of Transportation and Public Facilities
ASTM	American Society for Testing and Materials
°C	Celsius Centigrade
Caltrans	California State Department of Transportation
ConnDOT	Connecticut Department of Transportation
CRA	Crumb Rubber Additive
dB	Decibel
DOT	Department of Transportation
FDOT	Florida Department of Transportation
EPA	Environmental Protection Agency
°F	Degree Fahrenheit
Ft	Foot/Feet
HMA	Hot Mix Asphalt
INDOT	Indiana Department of Transportation
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
NYSDOT	New York State Department of Transportation
SAM	Stress Absorbing Membrane
SAMI	Stress Absorbing Membrane Interlayer
SDHPT	Texas State Department of Highways and Public Transportation
SRI	Stress Relieving Interlayers
US	United States
WSDOT	Washington State Department of Transportation

ABSTRACT

This report evaluates effectiveness of rubber-asphalt and ebonite-asphalt mixes based on a review of published literature, and unpublished reports. It discusses in detail various aspects of these mixes, including: different applications, physical properties, experiences of state highway agencies, and claimed advantages and problems associated with their use. The addition of ground tire rubber in asphalt significantly changes the physical properties of the mix. In general, physical properties, i.e., viscosity, elastic recovery, fatigue life, of rubber-asphalt mixes are much better than those of conventional asphalt.

Although rubber-asphalt mixes have superior physical properties, they have performed either only slightly better or equal to conventional asphalt mixes in the field. The salient problems associated with rubber asphalt mixes which restrict their use are: stickiness, high cost, and air pollution. The cost of rubber-asphalt mixes is much higher than conventional asphalts, and there is little evidence that rubber-asphalt mixes will have an increased service life sufficient to justify the high costs.

Based on the experiences of most of the states, it is recommended that use of rubber-asphalt mixes not be encouraged until INDOT acquires first hand results from pilot projects.

Ebonite-asphaltic mixes have possible applications assuming that the ebonite can be economically cleaned of lead contamination.

SECTION 1

INTRODUCTION

1.1 Background

Disposal of waste tires is becoming an increasingly serious problem, with large stockpiles all over the country. Current estimates by the Environmental Protection Agency (EPA) indicate that over 242 million scrap tires are generated each year in the U.S.

It is estimated that approximately 5 million waste tires are generated annually in the state of Indiana, with 40 stockpiles containing million of tires in different counties (Lovell et al., 1992).

Regulations have been developed to consolidate and stimulate alternative use technology of ground tire rubber. Tire Recycling Incentives Act (H.R.871 and S. 396) addresses the regulation and technology issues of ground tire rubber. Intermodal Surface Transportation Efficiency Act (1991, Section 1038) addresses the study and utilization of ground tire rubber wit asphalt mixes (Heitzman, 1992).

Tires are made with 30 different kinds of rubber and each portion of the tire has a different formulation or rubber, both natural and synthetic. The compositions of tire rubber makes them bulky, resilient, compaction resistant and non-biodegradable.

Therefore, scrap tire piles pose two significant threats to the public: fire hazard, and health hazard.

The use of tire rubber as an additive in asphalt pavement mixes has been proposed to recycle the rubber and preserve the natural sources. Pilot projects have been developed to evaluate the effectiveness of rubber-asphalt by 45 of the 50 states in the U.S. since 1960. In this regard, Indiana Department of Transportation (INDOT) constructed two test section to evaluate the effectiveness of rubber asphalt mix in 1991. One project, on SR-18 west of US-31 (in the east bound lanes) was constructed of four different combinations of modified rubber asphalt (1 to 3% rubber in asphalt by weight). It is too soon to draw any conclusions based on current performance.

Although many states have been involved with rubber-asphalt mixes, only a few have been totally satisfied with rubber asphalt mixes.

In general, the addition of crumb rubber to asphalt can be divided into two categories: wet process and dry process. The dry process blends the crumb rubber with the asphalt cement prior to incorporating the binder into the project. This binder can contain as much as 30% crumb rubber asphalt (CRA), (Ahmed, 1991). In wet process, the crumb rubber is mixed with the aggregate before mixture is charged with asphalt. This process is called modified rubber asphalt and generally contains an average of 3% (1 to 5%) rubber by weight in asphalt.

From the literature, it seems that the definition of rubber

asphalt mixes is not clear. Different researchers use different definitions for different combination of rubber asphalt mix. For example, Asphalt-rubber has been defined by ASTM D-8 as:

"a blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles."

The blend is typically formulated at elevated temperatures to promote chemical and physical interaction of the two constituents. Various petroleum distillates are sometimes added to the blend to reduce viscosity and enhance workability (Estakhri et al., 1992).

In most of the cases, regardless of the amount of rubber in the asphalt, the mix is called rubber-asphalt, asphalt-rubber, rubberized asphalt or rubber modified asphalt. Although definition is not the primary aim of this work, it is appropriate to clarify them.

Regardless of the amount of rubber in the mix, in the definition term rubber will be the adjective and modify asphalt as the noun. Herein, it is suggested that "rubber-asphalt mix" be the generic term regardless the amount of the rubber. "Rubber asphalt" denotes a mix which contains 15-30% rubber by weight. "Modified rubber asphalt" shall be used for mixes which contain up to 3% rubber. "Rubberized asphalt" shall be used for mixes which contain

rubber amounts between 3 and 15%. In this report, all rubber-asphalt mixes will be so defined. The classification is summarized in Table 1.

Table 1. Classification of Rubber-Asphalt Mixes

<u>Rubber Content</u>	<u>Classification</u>
0 to 5%	Modified Rubber Asphalt
5 to 15%	Rubberized Asphalt
15% and over	Rubber Asphalt

1.2 Objectives

Senate Bill 209 in 1991 is directed to Indiana Department of Transportation to explicitly study use of ground tire rubber and ebonite in asphalt. In this regard, to evaluate effectiveness of rubber-asphalt and ebonite-asphalt mixes, research was initiated to synthesize all existing information on both mixes based on published and unpublished literature.

1.3 Research Approach

In order to accomplish the stated objectives the following items were included:

- Review of all available published literature and unpublished reports on rubber-asphalt and ebonite-asphalt mixes.
- Communicate personally with other states transportation agencies to learn their experiences and recommendations
- Synthesis of the information that most fits the study objectives
- Report recommendations to the INDOT

SECTION 2

USE OF GROUND TIRE RUBBER IN ASPHALT MIXES

Rubber-asphalt mixes have been used for the following applications:

- rubber-asphalt joint/crack sealant
- rubber-asphalt stress absorbing membrane (SAM)
- rubber-asphalt stress absorbing membrane interlayer (SAMI)
- rubber-asphalt concrete
- rubber-asphalt concrete or modified asphalt hot mix

2.1 Joint-Crack Sealant

Perhaps the most common use of rubber-asphalt mix is as a joint/crack sealant; however, the use of the tire rubber in crack sealants is not high in volume. These mixes contain 15-30% crumb rubber with the asphalt cement.

There are several factors that effect the performance of joint/crack sealants. The choice of a sealant should take into account the pavement, type of crack or joint, shape/size of the crack or joint, time before next scheduled major rehabilitation, traffic volume, degree of pavement distress, and maximum/minimum temperatures (Estakhri et al., 1992). Arizona Department of Transportation (ADOT) has stated that although such rubber-asphalt mixes are initially more expensive than the conventional chip seal,

in the long run this material turns out to be economical. This is due to reduced maintenance and an increased life time (Schnormeier, 1983). Supporting evidence comes from other southern states, viz, Texas, Florida (Estakhri et al., 1992, and Roberts et al., 1989)

Although Roberts et al., (1989) reported that there is a trend away from using tire rubber in crack fillers, Texas State Department of Highways and Public Transportation (SDHPT) accepts a slightly wider variety of products. This allows other suppliers to enter the market and encourages the use of it.

2.2 Rubber-Asphalt Stress Absorbing Membrane (SAM)

A surface treatment using an asphalt-rubber spray application is called a "Stress Absorbing Membrane" (SAM). The purpose of SAM is to seal the underlaying cracks and prevent the entry of surface water into the pavement structure. Heitzman (1992) indicated that SAM can not resist the amount of strain that is typical of major transverse thermal cracks in asphalt concrete pavements or contraction joints in portland cement concrete pavements. SAM can resist and delay development of reflective cracks only when the cracks are inactive.

The amount of crumb rubber additive in binder is between 20-30% by weight of asphalt cement. In general, thickness of application is between 3/8 and 5/8 in. or 0.5 to 0.65 gallons per square yard of binder is applied to the surface (Singh and Athay,

1983).

Some states (Arizona, Texas, California) had good experiences with SAM, whereas others (Pennsylvania, Connecticut, Minnesota) reported that SAM's perform the same as conventional asphalt although the costs are twice as much as conventional asphalt (Schnormeier, 1986, Estakhri et al., 1992, Kirk, 1992, Mellot, 1989, Stephens, 1989).

2.3 Rubber-Asphalt Stress Absorbing Membrane Interlayer (SAMI)

Stress Absorbing Membrane Interlayer (SAMI) is a layer of rubber-asphalt sandwiched between existing pavement, and an overlay. SAMI was developed by the Arizona DOT in 1975 (Schnormeier, 1983). The difference between SAMI and SAM is that SAMI has an overlay whereas SAM does not. The purpose of SAMI is to act as a barrier to crack propagation from cracks in the underlying layers.

There are two-layer SAMI and three-layer SAMI. A two layer SAMI places the SAMI on the existing pavement and overlays the SAMI with 1 to 3 inches of hot mix asphalt (HMA). A three-layer SAMI begins with the placement of a leveling course of HMA. The SAMI is followed by an additional 1 to 3 inches of HMA. A three-layer SAMI is applied when there is deterioration of existing pavement cracks and joints (Heitzman, 1992).

It has been indicated that this type of interlayer is very effective in reducing stress concentrations above existing joints and cracks, and in retarding or eliminating reflection cracking due to thermal expansion or contraction of underlying rigid pavement. Delaying reflective cracking is the prior benefit of SAMI.

In general, SAMI is used when a pavement shows sign of significant fatigue cracks (Singh and Athay, 1983). Several states reported that SAMI performed many times better than conventional asphalt and is cost effective (Schnormeier, 1992). Other states reported SAMI performs only slightly better or the same as conventional asphalt, and doubles the cost. Some states (Arizona, Florida) reported that SAMI is cost effective because it requires less to maintain than conventional asphalt chip seals. However, comparison is often not possible because most of the projects did not have conventional asphalt control sections.

2.4 Rubber-Asphalt Concrete

Finely ground rubber tire particles may be mixed into the hot asphalt cement to create a rubberized asphalt binder. This binder is then added to a normal gradation of paving aggregate. This type of modification is called rubber-asphalt concrete. The rubber particles are smaller than those used in modified rubber asphalt. Generally, the rubber content in binder is 25 to 30% by weight. California Department of Transportation (Caltrans) has

been using rubber-asphalt concrete extensively for more than ten years (Kirk, 1992). It is reported that rubber-asphalt concrete is more durable and more abrasion resistant, when compared to a conventional dense asphalt concrete hot mix. After evaluating several projects with different thicknesses, Caltrans reported that the cost of rubber-asphalt concrete is 40% to 100% over conventional asphalt concrete. Although rubber-asphalt concrete costs 40% to 100% more than conventional asphalt, rubber-asphalt concrete is cost effective because costs to maintain are less.

2.5 Modified Rubber Asphalt Hot Mix (HMA)

Modified rubber asphalt was introduced by European engineers to increase skid resistance in the late 1960s (Esch, 1984, Eaton et al., 1991). Modified rubber asphalt was marketed by Swedish companies under the trade name of "Rubit". In the United States it was patented under the trade name of "PlusRide" in the 1970s.

The rubber ranges from 1 to 5% but in general 3% rubber is added to hot mix to replace some of the mix aggregates. The overall mix consists of blending larger rubber particles, 1/16 up to 3/8 in., compared to particles used in the asphalt rubber concrete. The larger rubber particles are thought to act as elastic aggregates that flex on the pavement surface under traffic and contribute to ice disbanding (Eaton et al, 1991).

SECTION 3

PHYSICAL PROPERTIES OF RUBBER ASPHALT MIX

3.1 Viscosity

Viscosity at any given temperature and shear rate is essentially the ratio of shear stress to shear strain. At high temperatures (i.e., 275 °F) asphalt cements behave as simple Newtonian liquids, whereas at low temperatures asphalt cements behave like non-Newtonian liquids. This is due to the fact that at high temperatures the ratio of shear stress to shear strain is constant, however, this ratio is not constant at low temperatures (Roberts and et al., 1991).

Standard ASTM test procedure requires measurement of the viscosity of asphalt cement at 140 °F (ASTM D2171) and 275 °F (ASTM D2170) by using a capillarity viscometer. The standard unit of measurement for viscosity is the poise and the lower the number of poises, the less viscous is the material. Table 2 presents ASTM requirements for viscosity graded asphalt cement.

The temperature of an asphalt is an indicator of potential construction and performance problems. High temperature-susceptible asphalts are associated with "tender" pavements during construction and with increased low temperature cracking and high temperature rutting after construction (Diringer and Smith, 1985). Temperature susceptibility of viscous graded asphalt cements is presented in Figure 1.

Table 2. ASTM Requirements for Viscosity Graded Asphalt Cements (D 3381-83) (After Roberts et al., 1991).

Note—Grading based on original asphalt.

Test	Viscosity Grade				
	AC-2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 140°F (60°C), P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	4000 ± 800
Viscosity, 275°F (135°C), min. cSt	80	110	150	210	300
Penetration, 77°F (25°C), 100 g, 5 s, mm	200	120	70	40	20
Flash point, Cleveland open cup, min. °F (°C)	325 (163)	350 (177)	425 (219)	450 (232)	450 (232)
Solubility in trichloroethylene, min. %	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:					
Viscosity, 140°F (60°C), max. P	1250	2500	5000	10 000	20 000
Ductility, 77°F (25°C), 5 cm/min, min. cm	100 ^a	100	50	20	10

^a If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a pull rate of 5 cm/min.

TABLE 2 Requirements for Asphalt Cement Viscosity Graded at 140°F (60°C)

Note—Grading based on original asphalt.

Test	Viscosity Grade				
	AC-2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 140°F (60°C), P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	4000 ± 800
Viscosity, 275°F (135°C), min. cSt	125	175	250	300	400
Penetration, 77°F (25°C), 100 g, 5 s, mm	220	140	80	60	40
Flash point, Cleveland open cup, min. °F (°C)	325 (163)	350 (177)	425 (219)	450 (232)	450 (232)
Solubility in trichloroethylene, min. %	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:					
Viscosity, 140°F (60°C), max. P	1250	2500	5000	10 000	20 000
Ductility, 77°F (25°C), 5 cm/min, min. cm	100 ^a	100	75	50	25

^a If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a pull rate of 5 cm/min.

TABLE 3 Requirements for Asphalt Cement Viscosity Graded at 140°F (60°C)

Note—Grading based on residue from rolling thin-film oven test.

Tests on Residue from Rolling Thin-Film Oven Test: ^a	Viscosity Grade				
	AR-1000	AR-2000	AR-4000	AR-8000	AR-16000
Viscosity, 140°F (60°C), P	1000 ± 250	2000 ± 500	4000 ± 1000	8000 ± 2000	16000 ± 4000
Viscosity, 275°F (135°C), min. cSt	140	200	275	400	550
Penetration, 77°F (25°C), 100 g, 5 s, mm	65	40	25	20	10
% of original penetration, 77°F (25°C), min	...	40	45	50	52
Ductility, 77°F (25°C), 5 cm/min, min. cm	100 ^a	100 ^a	75	75	75
Tests on original asphalt:					
Flash point, Cleveland open cup, min. °F (°C)	400 (205)	425 (219)	440 (227)	450 (232)	460 (238)
Solubility in trichloroethylene, min. %	99.0	99.0	99.0	99.0	99.0

^a Thin-film oven test may be used but the rolling thin-film oven test shall be the reference method.

^a If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a pull rate of 5 cm/min.

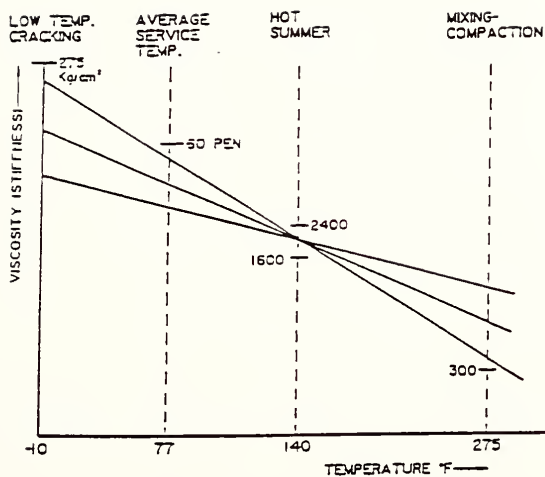


Figure 1. Temperature Susceptibility of Viscosity Graded Asphalt Cements (After Roberts et al., 1991).

Huff and Vallergera (1981) carried out research to test physical properties of rubber-asphalt mixes. The tests were performed on AR-4000 asphalt and AR-4000 blended with the extender oil and ground rubber. Table 3 presents the test results. It can be concluded that the influence of the rubber on the asphalt is to decrease its susceptibility to temperature. Rubber particles swell when heated in asphalt. The extent of this swelling, which affects the viscosity of a material, is a function of the blending temperature. The improvement in viscosity is substantial at the high temperatures. Reducing temperature dependence of viscosity and increased adhesion are the most promising effects of modified rubber asphalt use (Stephens, 1989, and Schnormeier, 1986).

If heat is maintained for a prolonged time, during the mixing of rubber with asphalt cement, the rubber may break down, resulting in an undesirable decrease in viscosity. Excessive material viscosity causes asphalt to fail due to too-low blending temperature (Allen and Turgeon, 1990, and Maupin, 1992). Dense-graded friction course mixtures are generally more susceptible to changes in binder content than open-graded asphalt.

The effect of rubber on viscosity was determined by Roberts et al., (1989). Figure 2 presents the effects of rubber content on viscosity. As can be seen from Figure 2, viscosity increases with increasing rubber content, and the increase is exponential.

Pavlovich and Shuler (1979) measured the absolute average viscosity of rubber-asphalt (25% rubber and 75% asphalt) to be

Table 3. Consistency-temperature Characteristics of Asphalt rubber Material (After Huff and Vallerga, 1981)

Property	Test Method	AR-4000 Asphalt	Asphalt-Rubber Material ^a
Penetration	ASTM D-4		
39.2° F		9	17
77.0° F		76	101
Softening point (ring and ball) (° F)	ASTM D-36	120	132
Dynamic viscosity at 140° F (poises)	ASTM D-2171	1800	7380
Kinematic viscosity (cSt)	Brookfield		
165° F		-	165 000
170° F		45 600	-
190° F		6 200	-
212° F		1 984	-
230° F		860	-
250° F		450	-
265° F		-	3 400
277° F		194	-
310° F		82	-
330° F		58	-
350° F		42	912
400° F		-	720

^aContains 78.4 percent AR-4000 asphalt, 1.6 percent extender oil, and 20 percent rubber blend.

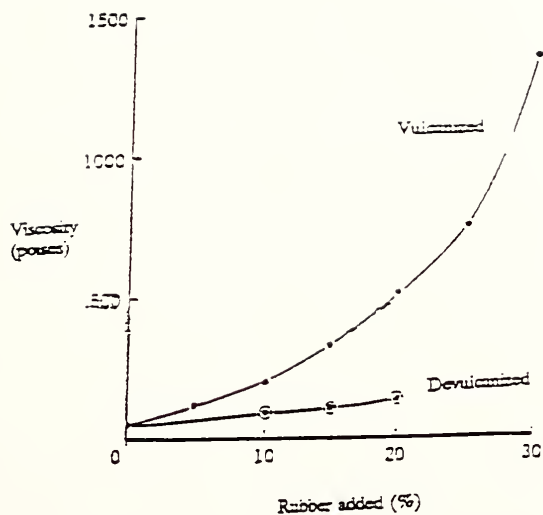


Figure 2. The Effect of increasing of Vulcanized and Devulcanized Rubber on Viscosity (After Roberts et al., 1989).

146,000 poises with a range from 27,000 to 475,000 at 140 °F. Unaged asphalt averages only 6,130 poises. Thus the increase in absolute viscosity is two orders of magnitude. Piggott et al., (1977) also showed that the addition of 5% rubber by weight of the total binder would increase the asphalt viscosity at 200 °F by 10-15 percent.

Roberts and et al; (1989) reported that during the asphalt and rubber blending operation, viscosity can be controlled by diluting the blend with petroleum distillates or aromatic extender oil.

On the other hand, Maupin (1992) presented relationships between viscosity and time with three different rubber contents for coarse and fine crumb rubber. Figures 3a,b present the Maupin (1992) results. As can be seen in the Figures, there is considerable variation in the test results, and there are no significant differences in viscosity for both rubber types.

Time and temperature are the factors that affect the viscosity of rubber asphalt blends. Roberts et al., (1989) indicated that the viscosity of rubber asphalt mixes is reduced as temperature and time are increased beyond the time required to produce the initial reaction between liquid asphalt and solid tire rubber. Figure 4 shows the effect of digestion time on viscosity of rubber-asphalt mix. Schnormeier (1986) presented field viscosity data for conventional asphalt and rubber-asphalt. Although viscosity of rubber-asphalt is almost constant, the viscosity of conventional asphalt changes significantly with time.

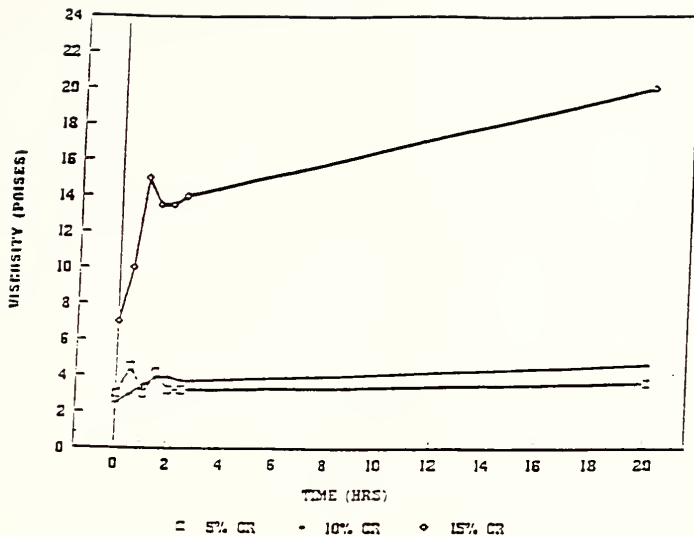


Figure 3a. Effect of Coarse Crumb Rubber on Viscosity with Increase of Time (After Maupin, 1992).

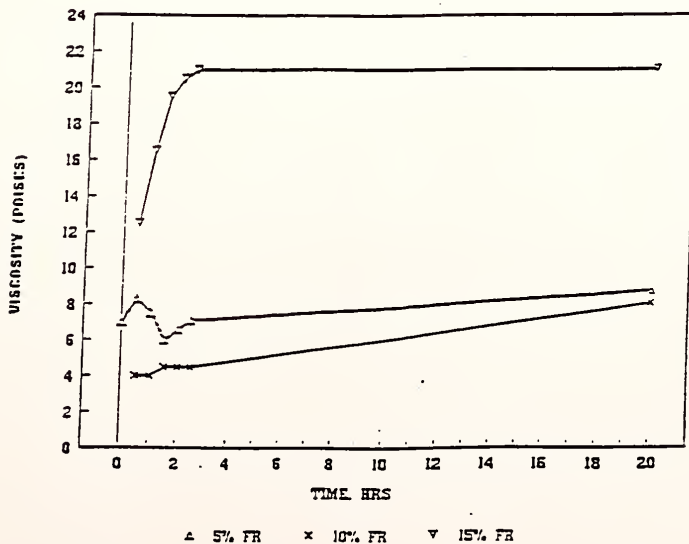


Figure 3b. Effect of Fine Crumb Rubber on Viscosity with Increase of Time (After Maupin, 1992).

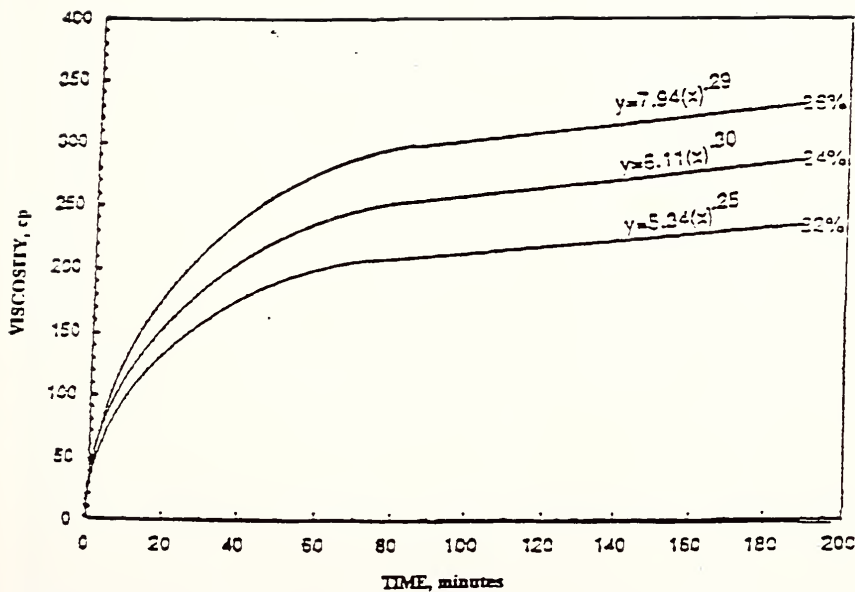


Figure 4. Effect of Digestion Time on Viscosity of Asphalt-Rubber Mix (From Roberts et al., 1989).

3.2 Fatigue Resistance

Fatigue resistance is the ability of a material to resist repeated loads that, in this case, can induce tensile strains which lead to cracking. The asphaltic mix should not crack when subjected to repeated loads over a period of time. Alaska Department of Transportation and Public Facilities (ADOTPF) performed several tests on modified rubber-asphalt (rubber content ranged from 1 to 3%) at 10 °C (50 °F) and -6 °C (21 °F) to test for fatigue properties. ADOTPF concluded that, based on fatigue, the modified rubber asphalt is superior to conventional mixes. Figures 5a,b show the laboratory fatigue curves for 10 °C and -6 °C. Although modified rubber asphalt gives better fatigue life than conventional asphalt, it should be noted that these differences are more pronounced at -6 °C than at 10 °C (Roberts et al., 1989).

Roberts et al., (1989), Piggott and Woodhams (1979) and Jimenez and Meier (1985) also concluded that rubber in asphalt significantly improves the fatigue life, and the addition of 5% rubber to HMA systems probably doubles the fatigue life. Robert et al., (1991) also performed series of tests to investigate the properties of rubber-asphalt mix. Figures 6a,b show the mean resilient modulus for 0.05 and 0.1 second loading time. As can be observed from the Figures, the mean modulus decreases with increasing of rubber content. It is also important to note that with decrease in temperature the mean resilient modulus increases. These results are very similar to those Takallou et al., (1985) and

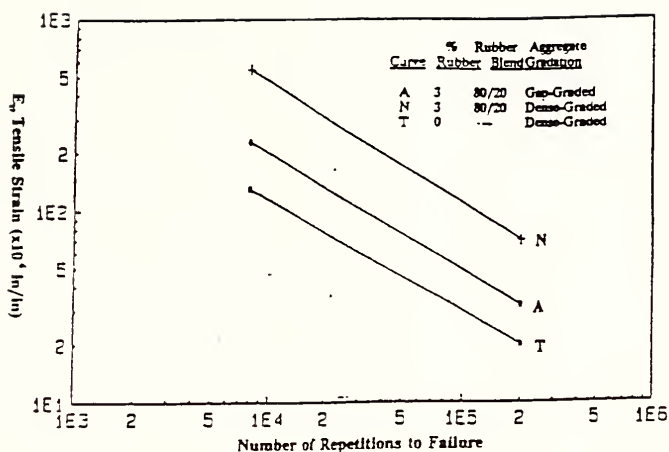


Figure 5a. Laboratory Fatigue Curves at -6 °C (After Takallou et al., 1985).

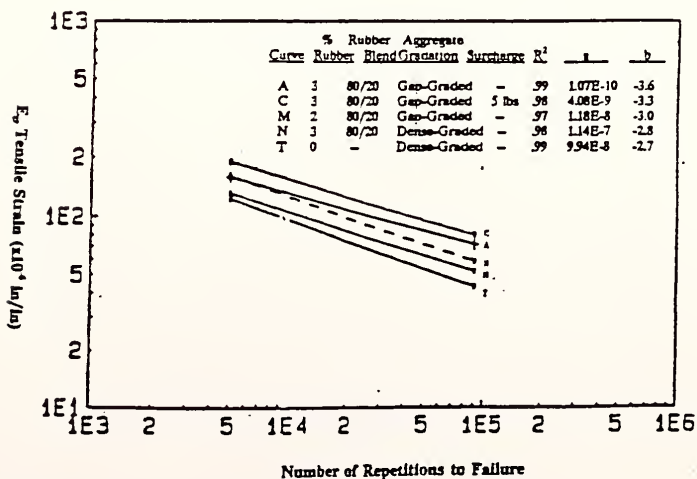


Figure 5b. Laboratory Fatigue Curves at 10 °C (After Takallou et al., 1985).

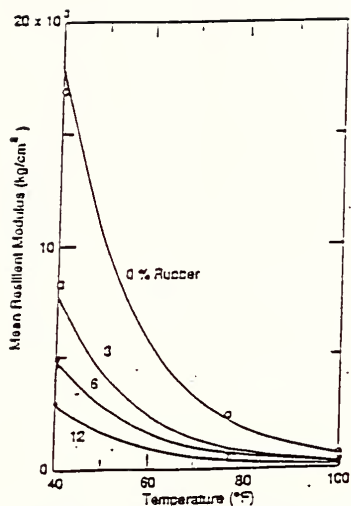


Figure 6a. Mean Resilient Modulus for a 0.05-Second Load Time of Various for Different Rubber Content (After Roberts et al., 1991).

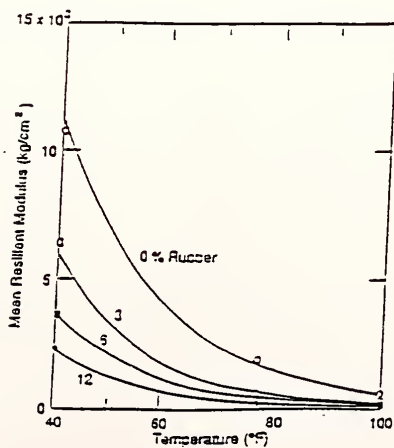


Figure 6b. Mean resilient Modulus for a 0.10-Second Load Time of Various for Different Rubber Content (After Roberts et al., 1991).

Stuart and Mogawer (1991). It can also be concluded that the resilient modulus increases with decrease in temperature and, as the load time increases, the resilient modulus decreases or the mix yields longer loading times. Roberts et al., (1989) recommended that laboratory test results should not be translated directly to the field, although improvements would be expected.

3.3 Void Ratio

Void ratio is one of the most important properties of the asphalt mix. The amount of voids significantly affects the performance of a mixture because if the void ratio is too small, the mix can have durability problems and if void ratio is too large, the mix can have stability problems. The voids in the total mix for compacted dense graded HMA is between 3 and 5% (Roberts et al., 1991).

The ADOTPF performed several tests to find the critical rubber content to achieve the lowest void ratio for rubber modified asphalt. Figure 7 presents the test results, where it can be seen that as rubber content increases, so does void ratio. As void ratio decreases, asphalt content increases. It was concluded that 2.5% is the most economical quantity of rubber in asphalt for modified rubber asphalt. Takallou et al, (1986) stated that the fatigue life of modified rubber asphalt increased with increasing void ratio, although this is contrary to the conventional relationship between void ratio and fatigue life.

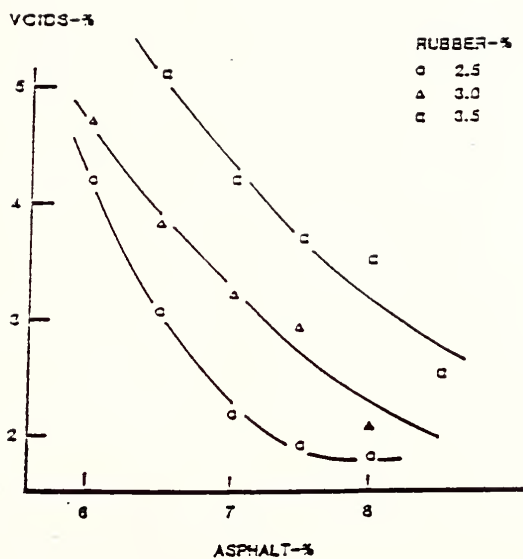


Figure 7. Effects of Rubber Content Variations on Percent Voids in Mix (After Esch, 1984).

3.4 Elastic Recovery

Oliver (1981) showed that for tire retread buffings, the elastic recovery strain increases linearly with increasing rubber content. Figure 8 shows the relationship between rubber concentration and elastic recovery. Elastic recovery increases with both temperature and digestion up to 220 °C. There is no further increase for 2-hour synthetic rubber digestion and a significant reduction in elastic recovery occurs for the 1-hour and 2-hour digestion above 240 °C.

3.5 Rubber Types

Rubber type is one of the factor that effects the properties of rubber-asphalt mixes. When asphalt cement and crumb rubber asphalt (CRA) are blended together, there is an interaction between the materials. Reaction between asphalt cement and CRA is influenced by temperature at which blending/reaction occurs, the length of time the temperature remains elevated, and the type and amount of mechanical energy (Heitzman, 1992). Other factors are also important, such as particle shape and size, rubber type and rubber gradation. Particle structure is the most important one (Takallou et al., 1985).

The rate of reaction between CRA and asphalt cement can be increased by increasing the surface area of the CRA. Oliver (1981)

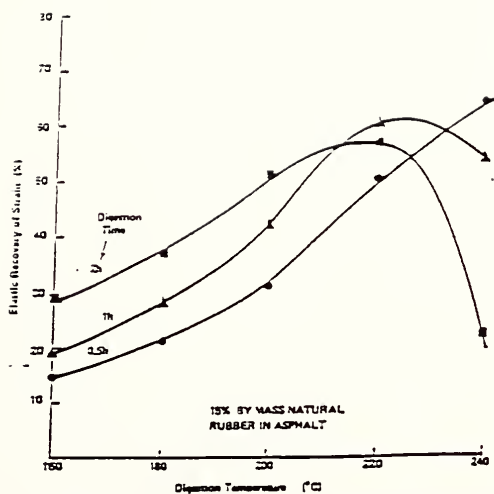


Figure 8. Effect of Time and Temperature of Digestion on Elastic Recovery for Natural-Rubber Tire Buffings (After Oliver, 1981).

showed the change of elastic recovery with particle size. See Figure 9. Oliver (1981) concluded that improvement in elastic recovery is due to the difference in morphology of the particles, with smaller particles being more porous and the larger particles having more flat surfaces. This is most likely due to the fact that the rate of swell of the rubber for the smaller particle size is much greater than that of the large particles. Therefore, it would be desirable to use fine particle sizes rather than large particle sizes.

It has been shown that the minus No. 25 to plus No. 40 crumb rubber, when mixed with asphalt and held at a temperature of 190 °C for approximately 20 minutes swells to approximately twice its original volume (Morris and McDonald, 1976). Besides swelling, rubber particles become much softer and more elastic. These phenomena are due to chemicals and physical reactions between the resins in the asphalt and rubber.

Takallou et al (1986) stated that the mixture with fine rubber has the highest modulus and lowest fatigue life, and the mixture with coarse rubber has the lowest modulus and highest fatigue life. For example, gap-graded aggregate mixtures with a blend of 80% coarse and 20% fine rubber has the lowest modulus and highest fatigue life at 10 °C and -6 °C.

It was found that large quantities of rubber (> 20%) are required to produce the desired effect i.e., to form a matrix. The resulting mass had a viscosity much too high for most conventional asphalt applications (Huff and Vallerga, 1981).

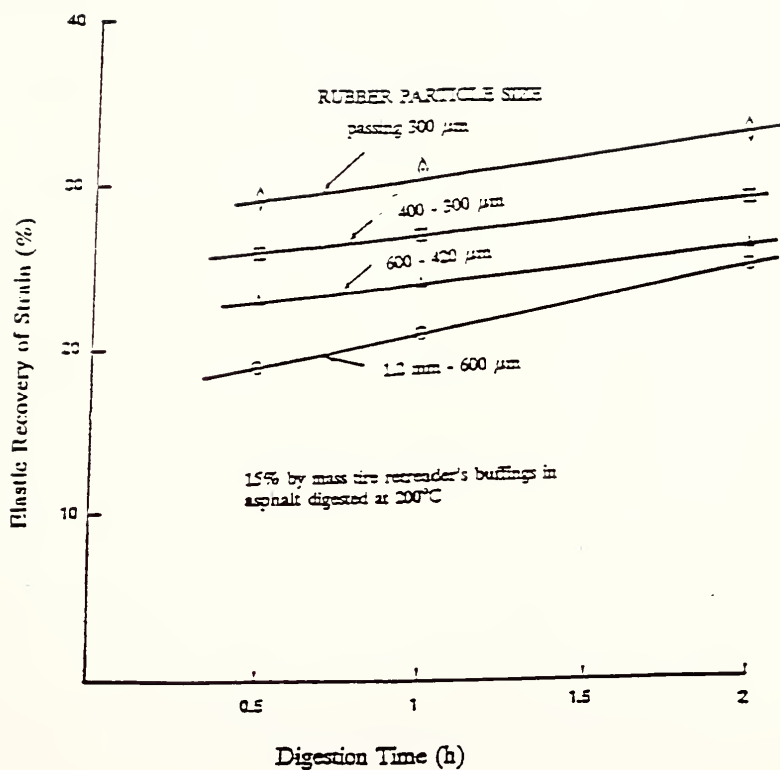


Figure 9. Effect of Particle Size on Elastic Recovery for Tire Retreader's Buffings (After Oliver, 1981).

SECTION 4

EXPERIENCES OF STATES WITH RUBBER-ASPHALT MIX

4.1 Connecticut

An extensive rubber asphalt mix experimental program was undertaken by the State of Connecticut and Civil Engineering Department of the University of Connecticut with the Federal Department of Transportation in 1977-78 (Stephens, 1989). Reclaimed tire rubber was incorporated into five different forms of pavement rehabilitation: thick overlays (4 cm), thin overlays (1.5 cm), chip seals, crack and joint sealing and stress relieving interlayers. Experiences of ConnDOT with each case are as follow:

4.1.1 Thick Overlays

The thick overlay was tested with one and two percent rubber at three levels of surface conditions at three level of traffic. ConnDOT had different experiences with different rubber content, with different traffic levels. One percent rubber reduced the longitudinal cracking, whereas two percent rubber increased the longitudinal cracking. Neither one nor two percent rubber performed better than conventional asphalt.

4.1.2 Thin Overlays

Thin overlays were placed at four locations. One percent of rubber reduced the amount of cracking by two thirds whereas further increases in the amount of rubber resulted in more cracking, although this evaluation is based upon limited data.

4.1.3 Chip Seals

Chip seals were tested at four different sites. Two of them were sand sealed a few months after construction. ConnDOT reported that at the three and four years evaluations, all rubberized seals were in better condition than the control sections. However, at nine years, all sections have been covered, and cracking in the new surfaces show less cracking when over the rubberized seals. ConnDOT also reported cracking in the two seals that were sand sealed when new was many times less than that in the regular sand-emulsion seals.

4.1.4 Surface Relieving Interlayers (SRI)

ConnDOT reported that the use of a SRI did not improve performance. Average performance with and without SRI was nearly the same. Rubber-asphalt layer as constructed did not act as stress reliever.

4.1.5 Rubber-Asphalt Joint Seals

Summer/winter joint and crack filling was compared. After an evaluation of nine years, ConnDOT reported that there was no differences in the apparent amount of joint sealant remaining in the pavement. Significantly more material placed in the summer remained than that placed in the winter.

4.2 Florida

The Florida Department of Transportation (FDOT) has experimented with rubber asphalt mix since late 1970s. Three projects were developed (from 1989 through 1990 (Ruth, 1991)) to evaluate the use of rubber in asphalt. The first pilot project was constructed in Gainesville in March 1989 using a dense-graded friction course containing 3, 5, and 10 percent rubber. FDOT reports that stickiness was a problem in this project.

The second project was constructed using 5 to 17 percent rubber in an open graded friction course on a state road near Starke in June 1989. FDOT concluded that 10% to 15% is best for open-graded friction courses.

The third pilot project was constructed on Interstate 95 in September 1990 using 10% rubber by weight. The purpose of this project was determine if rubberized asphalt could be blended and incorporated into an open-graded friction course mixture using a

prototype production blending unit on a conventional construction project. The project was completed without encountering any major problems of construction.

After construction and evaluating all of three pilot projects, FDOT concluded that tire rubber is feasible for friction course construction.

FDOT reported that using rubber in an asphalt binder will increase the cost 10%.

4.3 Michigan

Sixteen test and control sections were developed to evaluate the effectiveness of modified rubber-asphalt for reducing cracking and increasing the life of pavement overlays. This effort was undertaken by the Michigan Department of Transportation (MDOT) in 1978 and 1979 on M 46, in Saginaw County (DeFoe, 1985). In this project ground rubber crumb and reclaimed rubber was incorporated at two percentages levels, 0.5% and 1.5%. Only one of the sixteen sections showed lower cracking than conventional sections, and two of the sixteen section showed many more reflection cracks than conventional asphalt. It was also reported that 1.5% ground rubber sections were disintegrating and required frequent maintenance patching. MDOT concluded that no overall reduction in reflective cracking was achieved with any of the rubber mixtures. MDOT also reported that there was no significant differences in pavement

friction values measured for several mixtures used in the projects; however, some reduction in rutting was obtained with 1.5% ground rubber mixes.

MDOT recommended that tire rubber not be added to bituminous paving mixtures. Prior to considering future projects involving rubber additions, benefit-cost evaluations should be performed on the candidate mixtures.

4.4 Minnesota

The Minnesota Department of Transportation, MnDOT, has experimented with various uses of asphalt-rubber and modified asphalt-rubber (Allen and Turgeon, 1990). MnDOT has researched the use of asphalt rubber in seal-coats, interlayers, crack sealings, asphalt concrete systems, and rubber asphalt concrete. SAM and SAMI have been tested in two different projects. The test projects are located on state road 63 near Rochester, Xerxes Avenue in Minneapolis, and state road 10 from Hawley to Detroit.

MnDOT considered one of two SAM projects as a success whereas the other one was a failure. MnDOT concluded that when SAM is properly prepared and placed it may be cost competitive.

None of SAMI projects eliminated reflective cracking, however they did reduce the reflective cracking. MnDOT reported that the benefits do not appear to justify the cost increase.

4.5 New York

New York state Department of Transportation (NYSDOT) was required to evaluate the use of modified rubber-asphalt in the construction or improvement of state highways by state legislation in 1987 (White, 1990, Shook, 1990). NYSDOT was also required to investigate and report on the economic, environmental, and technical and other implications of the use of scrap motor vehicle tires in asphalt pavements. Pilot construction projects were placed with four different rubber contents at two different sites. Four rubber modified asphalt mixtures were included (Plus Ride, 1, 2, 3 % (by weight) rubber) in asphalt. Test sections were placed on Route 144 in the town of Bethlehem, Albany County and on Route 17 in the town of Deposit, Delaware County.

4.5.1 Albany County Project

The pavement was 20 years old, with 40-ft. joint spacing, and was located in a rural area. The daily traffic was 5,000 vehicles with 16% trucks. New pavement was overlaid on 8-inch Portland cement concrete pavement with a 1-inch asphalt overlay. Test pavement was a 0.75 to 1-inch leveling course and a 1.5 inch thick 6F top course.

4.5.2 Delaware County Project

The second test project was constructed on New York state Route 17 near the town of Deposit, Delaware County. The road was in poor conditions therefore before applying rubber-asphalt, a 2.5-inch thick leveling course, a 1.5-inch binder course and a 1.5-inch top course were constructed. This was followed by the placement of either conventional, PlusRide, 1, 2, or 3% rubber-modified mixes.

NYSDOT reported that although there is not enough experience with rubber asphalt mix, economical and environmental problems were present. The pilot projects showed increases in cost over the conventional asphalt, as shown in Table 4.

Table 4
Bid Price Relationship for
Rubber-Modified Asphalt Mixes
Compared to Conventional Asphalt Mix (After White 1990)

Mix ---	Albany County Project -----	Delaware County Project -----
1% Rubber	+ 50%	+ 114%
2% Rubber	+ 50%	+ 114%
3% Rubber	+ 50%	+ 114%
PlusRide	+ 50%	+ 129%

NYSDOT estimated that the use of rubber-asphalt mix would increase costs by 60% over conventional asphalt. The factors which cause rubber-modified asphalt to be more costly than conventional asphalt include: increase in the volume of asphalt cement binder, more costly aggregate (stone), filter gradation, more energy and

time, labor, equipment, and cost of granulated rubber. The rubber mixes tended to be sticky, adhering to the equipment and making release from the delivery truck bed more difficult. The stickiness increased with increases in rubber content.

Besides increased cost and stickiness, NYSDOT had environmental problems such as air pollution and odor. The report also express concerns about health effects because of the high carbon black and petroleum derivative content of the rubber in tires.

4.6 Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) has been evaluating the use of asphalt-rubber since the early 1960's (Mellot, 1989). PennDOT built two projects to evaluate, under actual field conditions, the effectiveness of a rubber-asphalt membrane interlayer (with 33% granulated, reclaimed rubber), SAMI in retarding the development of reflective-type cracking in bituminous overlays. The experimental projects were located in Center Counties, 307, 322 and Cambria and Indiana County, 314, 22. Both projects involved base repair, a leveling course, SAMI, and 0.5 in. of wearing surface course material. After evaluating numerous projects, PennDOT reported that SAM and SAMI performed as well as control section without the asphalt-rubber membrane. PennDOT concluded that SAM's and SAMI's are appropriate only in

asphaltic pavement courses, but that the use of SAM and SAMI should be discouraged because of the increased cost.

4.7 Washington

Washington State Department of Transportation (WSDOT) has constructed several pilot projects to evaluate rubber and PlusRide with asphalt and concrete pavement. Experiences of WSDOT with each application are summarized below.

4.7.1 Rubber-Asphalt Open-Graded Friction Course

This project was undertaken on I-5 in Vancouver, Washington, in 1986. A 1200 ft section of conventional open-graded pavement and a 3000 foot section of polymer-asphalt open-graded pavement were included as control sections (Allison, 1990). The rubber-asphalt binder consisted of 20% recycled vulcanized rubber and 80% AR4000W asphalt cement. The polymer-asphalt binder consisted of AC-20 paving grade asphalt rubberized with 1.2 to 2% by weight of virgin synthetic styrene-butadiene rubber.

After three months inspection there are no differences among the pavements although rubber-asphalt cost more than 51% over conventional asphalt.

4.7.2 Rubber-Asphalt Binder Stress Absorbing Membrane Interlayer (SAMI)

A pilot project was constructed to evaluate SAMI regarding to reflection of the cracks. WSDOT reported that rubber-asphalt SAMI slightly decreases the transverse reflection cracks but cost twice as much as paving grade asphalt.

4.7.3 PlusRide Asphalt and Concrete Pavement

WSDOT has constructed several pilot projects to evaluate PlusRide (Allison 1990, Schultz, 1987). WSDOT expressed its experiences as follow:

"It appears the PlusRide product does not stand up to its' developers claims. There is no evidence of better frictional properties, noise reduction or increased service life on this experimental project."

SECTION 5

EVALUATION OF THE CLAIMED ADVANTAGES OF RUBBER ASPHALT MIX

It has been claimed that rubber asphalt mix has several advantages. The reported benefits of rubber-asphalt can be summarized as follows (Ahmed, 1991, Takallou et al., 1986, Esch, 1984, Estakhri et al., 1992, Kirk, 1992):

- Reduce noise.
- Greater resistance to aging.
- Reflective and thermal cracking is reduced.
- Resistance to studded tire wear is increased.
- Higher viscosity than conventional asphalt.
- More durable.
- Recycling of used rubber tires.

The reported modified rubber asphalt advantages can be summarized as follow (Ahmed, 1992, Takallou et al., 1986, Kirk, 1992):

- Skid resistance increased
- Reduce noise
- Deicing
- Resistance to studded tire wear is increased.
- More durable
- Decrease stopping distance.
- Recycling used tires.

5.1 Skid Resistance increases

Addition of rubber in asphalt is said to increase the skid resistance of pavement. ConnDOT has performed several test to investigate skid resistance of rubber-asphalt (Stephens, 1989). After eight year evaluation, they reported their experiences as:

"For any one age, no significant differences are found between skid number for differed mixes. However, there is 97.5 probability that the skid numbers in 1980 are greater than in 1977 or 1978."

5.2 Deicing

It has been claimed that modified rubber asphalt has deicing properties because of increased flexibility and the action of protruding rubber particles. Deicing properties of the pavement increases with increase of rubber content. To test the deicing properties of modified rubber asphalt many projects were developed by several states; however, test results are in contradiction. After extensive research, Eaton et al., (1991) concluded that with increasing rubber content (i.e., an increase presence of larger particles on the pavement surface) there are increases in the incidence of cracking. Surface characteristics other than the presence of rubber particles does not appear to affect cracking. Takallou et al. (1985), reported that coarse rubber in asphalt is effective for ice removal and decreases stopping distance as much as 25%.

5.3 Reduce Noise Level

One of the primary advantages of rubber-asphalt is said to be the reduction of noise. It has been claimed that modified rubber-asphalt reduces the noise an order of 90% (10 Db) due to open graded design and the inclusion of crumb rubber (Arizona, Alaska). Sainton (1990) reported that noise reduction has been recorded up to 50% (3 Db) in France. Heerkens (1985) reports that open-graded rubberized asphalt reduces the noise level at least 3.5 Db compared to dense graded, whereas reduction is only 0.5 Db when compared with conventional asphalt. On the other hand, other states (New York, Wisconsin, Minnesota, Pennsylvania) reported that they did not record significant noise reduction. Standberg et al (1990) tested modified rubber asphalt (Rubit) in Sweden, for noise reduction. They reported that modified rubber asphalt surfaces emit noise equivalent to that of the reference surfaces. Standberg et al., (1990) concluded that traffic noise reduction can not be used as an argument for using modified rubber asphalt.

It is also important to note that the reporting of noise reduction values for various agencies are in contradiction. It seems from the available data that each agency followed different procedures and compared the results with different conditions. Therefore, it is hard, if not impossible, to draw any conclusions about noise reduction.

5.4 Decrease Stopping Distance

The ice control mechanism results from the flexing of the protruding rubber particles and the greater flexibility of the mix causes a breakdown of surface ice deposits under traffic action. Esch (1982) reported that PlusRide reduces the stopping distances 3 to 50% with an average of 25%. However, there are no significant data that support deicing of modified rubber asphalt.

5.5 More Durable

Arizona DOT believes that the durability of rubber-asphalt is much greater than conventional asphalt. They presented the following numerical evidence.

Rubber asphalt as a binder in hot mix has lasted for more than 15 years. Rubber-asphalt as a seal coat has lasted over 21 years. Schnormeier (1992) concluded that rubber-asphalt has 2 to 3 times the life of the standard asphalt. Texas State Department of Highways (SDHPT) reported that it is unlikely that rubber-asphalt would last 2 to 3 times longer than standard asphalt.

Durability of rubber-asphalt mixes improves due to reduced age hardening and improved retention of aggregate. Age hardening decreases due to anti-oxidants in the rubber and increased film thickness. Retention of aggregate improves due to increased film thickness and greater resiliency (Ruth, 1991).

While most of the states reported that rubber asphalt mixes

performed as well as conventional asphalt or slightly better, there is no evidence that rubber asphalt mix would last longer than conventional asphalt.

5.6 Reflective and Thermal cracking is reduced

It has been argued that reflective and thermal cracking can be reduced with stress absorbing layers such as SAM and SAMI. SAMI is especially effective in reducing stress concentrations above existing joints and cracks. SAMI reduces reflection cracking by cushioning or dissipating the stress from the underlying pavement before they are transferred to the overlay (Ahmed, 1991).

SECTION 6

PROBLEMS ASSOCIATED WITH RUBBER-ASPHALT MIX

The following problems are associated with the use of rubber-asphalt.

6.1 Environmental Problems

Potential environmental problems are smoking (fumes), from high temperature mixing, and presence of carbon black or other carcinogens in rubber.

Several states (California, Connecticut, Florida, New York, Pennsylvania) have reported that air pollution increases with adding rubber to hot mix asphalt (HMA). The magnitude of the air pollution increases with increase of rubber content in asphalt. Smith (1983) reported the air pollution during the placement of rubber-asphalt mixes as follow:

"A great deal of smoke was produced by the hot rubberized asphalt"

There is an increased tendency for smoke to be emitted as well as the creation of a burning rubber odor. White (1990) and De Laubenfels (1985) reported that a great deal of smoke was produced by hot rubberized asphalt during experimental projects. It is also reported that NYSDOT recommends that the potential health effects

be evaluated if use of rubber asphalt becomes widespread, due to the high carbon black and petroleum derivative contents of rubber.

6.2 Stickiness

Stickiness is one of the main problem associated with rubber asphalt mixes. Rubber asphalt mixes with high percentages of rubber content (higher than 3%) tend to adhere to the equipment and to truck beds. Extra care and water additives are required in rolling to prevent adherence to the rollers. Florida reported that stickiness of rubber asphalt mix increases with increasing rubber content. It is also reported that the process of cleaning equipment after using rubber asphalt mix is extensive and time consuming.

MnDOT reported that rubber asphalt mixtures are more susceptible to adverse weather or equipment problems occur. NYSDOT (White, 1990) reported that stickiness also makes it difficult to properly reduce pavement voids, which may cause early failure. Iowa Department of Transportation (IDOT) has reported that during the placement of rubber-asphalt mixes shoving and cracking of the mix became a problem as it was being rolled (Anderson, 1991).

6.3 Cost

All other conditions being equal, use of ground tire rubber costs approximately 60% more than conventional asphalt. If this is the case, it is estimated that using tire rubber in asphalt will cost \$11 for each tire. It is said that the cost will decrease by increasing usage of rubber asphalt mixes. The factors that increase the cost include: increased asphalt cement binder content, increased energy costs, increased cleaning expenses, increased labor cost, equipment modification, extra work to design and testing of samples mix.

Increased asphalt-cement binder content: An increase in the volume of asphalt cement binder is required when using rubber in asphalt. Rubber asphalt mixes need more costly aggregate (stone) and filter gradation. Roberts et al., (1989) indicated that at any given temperature rubber asphalt binders have higher viscosity than conventional asphalt.

Increased energy costs: The mixing temperature is increased with addition of rubber into the asphalt. The mixing temperature of the conventional asphalt generally is about 300 °F whereas that for rubber asphalt mixes is about 375 °F. The higher the temperature, the more energy consumed. Therefore, rubber asphalt mixes will cost more than conventional asphalt due to energy requirements.

Increased cleaning expenses: Because of its stickiness, rubber asphalt mix adversely affect the beds of trucks and other equipment during placement. Thus, additional labor and cleaning materials are required.

Labor: NYSDOT (White, 1990) reported that during the pilot projects additional labor was required to feed the belt and to place the bagged rubber in the aggregate hopper at the time of mixing.

Equipment Modification: During construction of pilot projects, rubber bags were introduced to the binder by hand. If rubber will be used continuously, additional conveying equipment should be designed to decrease labor and obtain homogeneous mix.

Rubber-asphalt mixes require more mixing time and time to test the samples than conventional asphalt. Furthermore, it has been reported that working with rubber asphalt mixes is much slower than conventional asphalt.

It is likely that increase in the use of rubber asphalt mixes will decrease the cost differential. However, other rubber tire disposals are being developed. NYSDOT and ConnDOT report that energy production facilities for tire scraps have been built in New York and Connecticut. Two of these plants plan not only to use the scrap tires in their states but neighboring states scrap tires as well.

Because of the many factors influencing the life of any pavement surface, it is very difficult to assess the cost-effectiveness of rubber asphalt mixes. However, at this the use

of tire rubber in asphalt is not economical since there is no strong evidence that rubber asphalt lasts longer or performs better.

SECTION 7

USE OF EBONITE IN ASPHALT PAVEMENT

A variety of waste materials has been used in asphalt pavements for years to recycle natural sources, get better performance, and offset the rising cost of quality natural aggregates by Indiana Department of Transportation (INDOT). In this respect, INDOT was directed to initiate research on uses of ebonite in asphalt pavements with Senate Bill 209 (1991).

Ebonite is discarded battery cases which are made of rubber, plastics, and asphalt with various of types of filters and fiber (Manke 1965). Apparently there are two types of ebonite: hard and soft. Hard ebonite contains about 32% sulfur (S), whereas soft ebonite contains only 3% S. Ebonite is hard at ordinary temperatures but softens at about 140 °F and becomes flexible at 212 °F. In general, ebonite is hard, nonelastic, is resistant to abrasion and has high impact resistance (Martell, 1958).

Amounts of heavy metals in ebonite are of major concern since. Apparently the amount of the lead within ebonite particles is above the Environmental Protection Agency (EPA) and Indiana Department of Environmental Management (IDEM) requirements. However, Cole (1992) states that the new developed cleaning process qualifies ebonite to be nonhazardous disposal. According to the EPA definition if a waste material contains more than 210 ppm lead the waste is considered hazardous waste material.

Although Collivignarelli et al., (1986) reported that the purity of ebonite depends upon the size of the particles (the smaller the size, the higher the purity), they did not give any specific relationship. The purity is also function of the cleaning process.

There is almost no available literature on ebonite. No state has had experience with ebonite in asphalt pavements according to Ahmed (1991). Therefore it is difficult, if not impossible, to draw any conclusions about usage of ebonite in asphalt pavements.

ACE Battery Company of Indianapolis has sent two different ebonite samples with two different grain size (coarse and fine grained samples). The grain size distribution of the samples are given in Figure 10. Both fine and coarse samples are poorly graded according to the Unified Soil Classification System (USCS).

Texas Transportation Institute (TTI) evaluated physical properties of ebonite in 1965 (Manke et al., 1965). According to Manke et al., (1965) ebonite has both desirable and undesirable properties for use in asphalt pavements. The desirable properties of ebonite as aggregate are strength, light weight, angular, and resistant to abrasion. Undesirable properties of ebonite (battery cases) are flammability, smooth-sided and containing lead contamination.

Manke et al (1965) concluded that, ebonite can be used as aggregate in asphalt pavement. The amount of the ebonite should be determined by experiment. However, a 10 to 20% usage the physical properties of ebonite.

Grain Size Distribution for Ebonite Samples from ACE Battery

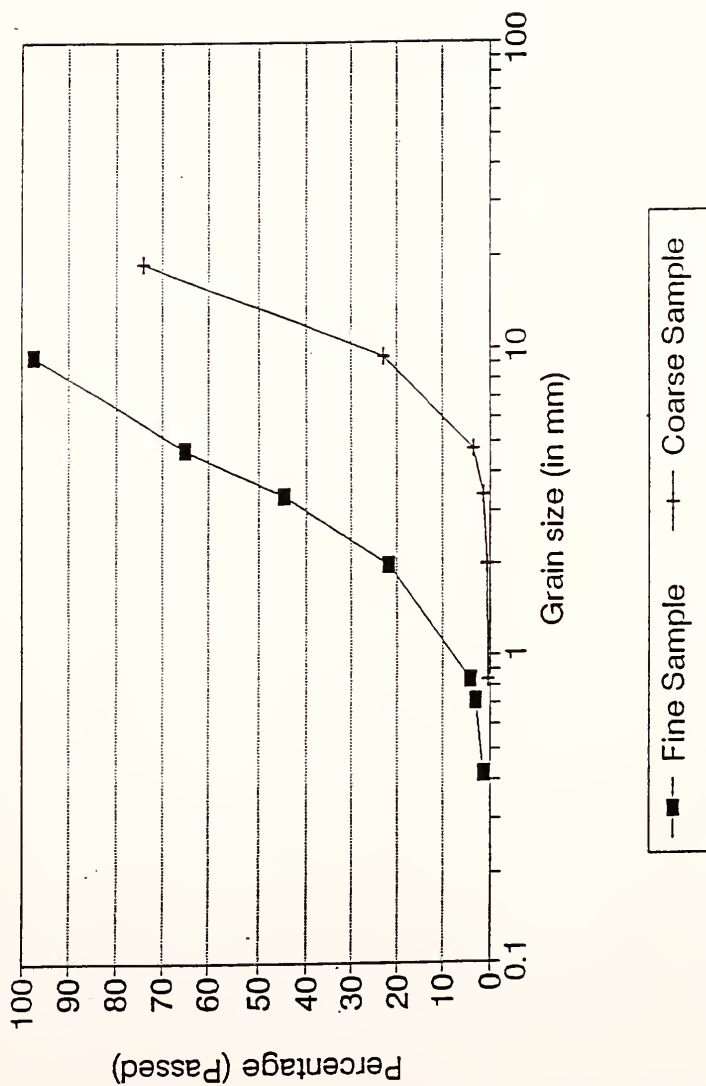


Figure 10. Grain Size Distribution of Ebonite Samples

Environmentally speaking, the use of ebonite questionable due to the presence of lead. Therefore, it would not be realistic to use ebonite without reducing its lead content.

Ace Battery Company of Indianapolis and U.S. Bureau of Mines (Cole, 1992) have been argued that the amount of lead in ebonite meet with EPA specifications. If it is the case, it can be said that there would not be any hazardous problem. This would need to be accomplished under IDEM and EPA specifications.

SECTION 8

DISCUSSION

Use of ground tire rubber with asphalt and its advantages and disadvantages have been presented. Some of the case histories support the use of ground tire rubber with asphalt whereas some studies discourage the use of ground tire rubber in asphalt.

Some physical properties of rubber-asphalt mixes that have been presented are superior in terms of both design and performance of the pavement. It should be stressed that most superior properties of rubber-asphalt mixes reported are based on laboratory studies. None of these properties have been properly verified in the field, which is a necessary step.

California Department of Transportation (Caltrans) has been doing extensive research on rubber-asphalt mixes products for 13 years. Based upon extensive field test results Kirk (1992), states their experiences with rubber-asphalt mix products as follow:

"At this point in time, we are doing just that, guessing; but, these guesses are being made on selected experimental projects".

Therefore, it is too soon to draw any solid conclusion based on any laboratory and field test results.

It is also important to note that reported test results are in contradiction both for advantages and disadvantages. For example,

ADOTPF claimed that modified rubber asphalt reduces the noise level up to 90% whereas the amount of the noise reduction is only up to 50% in France. Nonetheless, in Sweden, home of asphalt rubber, it is argued that modified rubber asphalt does not reduce the noise level (Standberg et al., 1990). It is well known that gradation type is one of the factor that controls noise level. For example, everything being equal, noise level of open graded pavement will be less than that of dense graded pavement. Therefore, comparison of noise reduction must be with same type of gradation.

It has been argued by ADOT that SAMs are extremely effective whereas PennDOT and NYSDOT recommended that discourage the use of SAMs due to their poor experiences. The Minnesota Department of Transportation reported that SAMs perform the same as or slightly better than conventional asphalt.

There are differences not only in laboratory and field test results but also the reasons why ground tire rubber would be used in asphalt. Namely, to enhance the properties of the resulting mixture or merely to dispose of the discarded tires. The Wisconsin DOT has expressed the opinion that the use of rubber tires in asphalt has been a political decision rather than a technical one (Jaskaniec, 1990).

Although several factors contribute to the effectiveness of rubber asphalt mixes, weather conditions and adequate preparation and construction procedures are the two most important factors.

It appears that every state used rubber in asphalt with

different procedures. Most of the states experimented with rubber modified asphalt whereas, Arizona and Texas experimented with rubber asphalt. As earlier explained in this report rubber modified asphalt contains only up to 5% rubber whereas rubber-asphalt contains more than 20% rubber. Therefore, it would be expected that properties of these two products would be different.

It is the opinion of the author that some of the differences come from procedures followed during the tests. Therefore, it would not be realistic to draw any conclusion based on any of the state results. To reach an ultimate conclusion, long term test results should be evaluated, considering every aspect of rubber asphalt mixes.

Under dry weather conditions badly cracked pavement can remain structurally sound for a long time whereas this is impossible in wet region conditions due to migration of rain through pavement. Arizona and Texas have dry weather conditions; therefore, climatic conditions can have significant effect on pavement structures. On the other hand, it is difficult to explain good experiences of Alaska with modified rubber asphalt. Poor experiences of almost all midwest states with rubber asphalt mixes are not explained by climatic conditions. There must be another factors that effect the performance of rubber-asphalt mixes.

Most of the states had experiences with rubber asphalt mixes when rubber asphalt mixes were still in an experimental stage. Reported negative performance of many pilot projects may be related to improper construction and design practices rather than the

material itself. At the time of application, rubber asphalt mixes need to be well mixed and kept at proper temperature to avoid roping and spreading problems and to obtain required embedment (Schnormeier, 1983).

It has been reported that rubber asphalt mixes have the poorest appearance in the first year but improve with age, whereas asphalt has its best appearance in the first year and deteriorates in its quality with time. As most of the states, which had poor experiences with rubber asphalt mixes, prepared their reports soon after demonstration projects, therefore, it is too early to draw any conclusion about the effectiveness of rubber asphalt mixes.

The question arises as to why tire rubber should be used in asphalt. Should it be to get better performance or to dispose of excess scrap tires. If the answer is to get better performance then there is no convincing evidence that fully supports the use of ground tire rubber in asphalt. Rubber asphalt mixes are in an experimental stage; therefore, rubber asphalt mixes should not be increased in use until a longer service is proved. If the answer is to dispose of the scrap tires, then tire rubber should be used with large percentages in asphalt. For example, FDOT estimated that if 3% of tire rubber is used in asphalt, only 10% of tires would be used, which will not decrease the disposal problems significantly.

Perhaps use as a fuel source and raw material in production of other polymeric materials would be a much more effective way to dispose of scrap tires. Plants are using scrap tires as a fuel

source in California, Connecticut, New York. Kandal (1990) stated that Rubber Research Elastomers, Inc. of Minneapolis has developed a patented process for treating granulated tire rubber to produce a raw material for use in the production of other rubber products. In addition to the high cost and other uncertainties, rubber asphalt mixes can create some environmental problems due to carbon black. Environmental problems, must be resolved prior to the widespread use of ground tire rubber in asphalt.

SECTION 9

CONCLUSIONS

The followings can be concluded from the discussion on rubber asphalt mix products.

1. The rubber-asphalt and modified rubber asphalt mixes are two different products and have significantly different engineering properties.

2. Adding tire rubber into asphalt mixes significantly increases the viscosity of the mix. Viscosity increases with increasing rubber content. Viscosity of the mix also depends upon particle size of the rubber. The smaller the size, the higher the viscosity.

3. Laboratory results indicate that rubber in asphalt significantly increases the fatigue life of the mix. If the performance of the pavement is based on the fatigue, rubber-asphalt mixes are superior. Fatigue life of rubber-asphalt mixes increases with increasing void ratio, contrary to the conventional relationship between void ratio and fatigue life.

4. Type size and shape of the granulated rubber affect the properties of rubber asphalt mixes. It is desirable to use fine particle sizes rather than coarse sizes.

5. Most of the reported experiences by states are in contradiction due to following different procedures, differing placement procedures and having different climatic conditions. Therefore, it would not be realistic to draw any conclusion based on the experience of any one state.

6. In general, rubber asphalt mixes perform better or equal to conventional asphalt. However, rubber-asphalt mixes are more expensive than conventional asphalt and benefits to offset the increased cost have not been proven.

7. Some problems are also associated with rubber asphalt mixes such as environmental problems which could restrict use of tire rubber in asphalt.

8. Ebonite has both desirable and undesirable properties for asphalt pavement. Some amount of ebonite can be used with asphalt pavement materials if ebonite is cleaned from heavy metals.

SECTION 10
RECOMMENDATIONS

1. Longer life of rubber asphalt mixes has not been proven; therefore, at this stage, rubber asphalt mixes should be used sparingly in pavements until Indiana Department of Transportation (INDOT) finds experimental results favor the use of tire rubbers in asphalt.

2. If the aim of using tire rubber in asphalt is to dispose of tires, large amounts of tire rubber (above 25%) in asphalt would have to be used in order to reduce the amount of stockpiles. By using only small amounts of tire rubber (i.e. 3%) in asphalt stockpiles will not significantly reduced.

3. To reduce the amount of tire stockpiles, other usages of tires should be researched, such as fuel, lightweight highway embankments, retaining wall backfills.

4. Cleaned ebonite can be used in asphalt with pavement materials. However, ebonite should not be used before doing extensive research on it.

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